LASTING PROPERTIES OF CUT FOLIAGE[1]

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THE LENGTH of time that cut branches will retain their normal appearance and methods of increasing this period of time are of vital concern in modern warfare. Foliage is the principal raw material of military camouflage, and the way it is handled may well affect the life of the soldier or even the outcome of the battle. Simple guides to the use of cut foliage in camouflage, based upon extensive experimentation, have been prepared by the Harvard Camouflage Committee.[3] The present paper covers certain technical aspects of this research which may be of interest to the botanist and of value in peace time to those engaged in transplanting, in vegetative propagation, and in the use of fresh plant material.

SPECIES SURVEY

That cut branches of different species of plants vary a great deal in their ability to retain their normal appearance is apparent to the most casual observer. Nevertheless, little work has been done to evaluate carefully the lasting properties of the common plants, and to ascertain how long the foliage of a particular plant will retain its normal appearance under various conditions. Tests carried out indoors or in the greenhouse are of little value in predicting the behavior of plants exposed to full sunlight, high temperatures, and drying winds.

To supply this information, several thousand tests have been carried out with plants of the northeastern United States at the Harvard Forest, Petersham, Mass., with European and Asiatic species at the Arnold Arboretum, Jamaica Plain, Mass., and with tropical foliage at the United States Plant Introduction Garden, Coconut Grove, Florida. No attempt was made to cover all the important species of any region, but an effort was made to secure a representative sampling of the most common plants. Most of the

[1]This paper is a partial report of the results of investigations carried out by the Harvard Camouflage Committee, a voluntary inter-departmental organization of Harvard University, comprised of staff members of the Maria Moors Cabot Foundation for Botanical Research, Harvard Forest, Biological Laboratories, and Arnold Arboretum. The coöperating institutions made available the necessary facilities and covered all expenditures of the Committee.

[2]The authors wish to acknowledge the coöperation of the United States Plant Introduction Garden at Coconut Grove, Florida, and that of camouflage officers in the Corps of Engineers and other branches of the United States Army. Among the members of the Harvard Camouflage Committee, I. W. Bailey, Ernest Ball, P. R. Gast, R. J. Lutz, E. D. Merrill (Chairman), K. V. Thimann, and R. H. Wetmore gave freely of their time and energy to those phases covered by the present report.

[3]Harvard Camouflage Committee. Using cut foliage for camouflage. 2 manuals, 17 pp. and 19 pp. Illus. Harvard Forest, Petersham, Mass. 1943.

tropical plants tested were lowland species, particularly those native to coastal regions.

Sprays of cut foliage of a uniform size (6 to 8 feet in Petersham and 3 to 5 feet elsewhere) were exposed on stakes or racks to full sunlight and all weather conditions. Careful notes of the condition of the plants were taken several times a day during the critical stages of drying, and daily at other times until the branches were completely withered. Each species was tested with at least two treatments: (1) base of branch suspended in air, and (2) base of branch immersed in water. Every treatment was replicated (five times in Petersham and three times elsewhere) and was repeated until reasonably consistent results were obtained.

The greatest difficulty encountered in these species surveys was that of developing a system of rating foliage condition that would give comparable results throughout the great variety of plants tested. Cut foliage reacts in many ways to drying out and death. Many plants brown; others, like *Viburnum,* blacken; still others, like *Eucalyptus* and some palms, whiten; and others, like pin cherry, develop autumn coloration. Some crisp, while others merely wilt. After initial trials, the following classification was set up and successfully used in dividing all plants into five broad classes of drying.

CLASS I. Normal. No evidence of wilting or injury.

CLASS II. Slight wilt. Essentially normal in appearance but evidence of drying such as (1) slight drooping of leaves, (2) marked wilt of young growing tips only, or (3) slight discoloration, usually on undersides of leaves only.

CLASS III. General wilt. Foliage wilted, but little or no (less than ten percent) crisping. Obviously abnormal in appearance, but foliage still essentially green and soft. Browning largely confined to undersides of leaves.

CLASS IV. Partially crisp. Marked crisping and discoloration of foliage, but more than fifty percent of leaves essentially green and soft.

CLASS V. Crisp. More than fifty percent of leaves crisp and discolored. Discoloration may consist of browning, blackening, whitening, autumn coloration, or merely marked fading.

During a given test, all foliage passed from Class I to Class V. At the time of each observation, a single rating was given for each species unless the variation was so great that single branches of the same species fell into different classes. The time necessary to pass through various classes was different for different plants. This difference might be used to explore certain physiological properties of species. The dividing line between Class II and III was taken as the limit of usefulness of plant material to be recommended for camouflage purposes. Selecting of any other point would result in a different ranking of species.

As a result of these surveys, it was possible to rate the relative lasting qualities of the different species, both with and without water (Tables 1 and 2). The values given for each plant cannot be considered as exact, since the lasting qualities of any plant are affected by many factors. The relative ranking of the different species, however, is reasonably accurate, and the values presented are a good indication of the number of days each species will last if exposed to full sunlight in the middle of the growing

TABLE 1.

LASTING OF CUT TEMPERATE FOLIAGE

Days in sunlight without water	Species	Days in sunlight with water
12 or more	Picea Abies (Norway spruce)	14–21
	Pinus resinosa (red pine)	14–21
	Pinus silvestris (Scotch pine)	12–16
	Pinus Strobus (white pine)	10–14
6–12	Picea glauca (white spruce)	14–21
	Juniperus communis (common juniper)	14–21
2–6	Tsuga canadensis (hemlock)	4–10
	Larix decidua (European larch)	4–8
	Larix Kaempferi (Japanese larch)	4–8
1–2	Malus pumila (apple)	6–10
	Ligustrum vulgare (common privet)	6–10
	Ligustrum ovalifolium (California privet)	6–10
	Vaccinium spp. (blueberry)	4–8
	Quercus velutina (black oak)	3–6
	Quercus borealis (red oak)	3–6
	Crataegus Oxyacantha (English hawthorn)	2–4
	Acer saccharum (sugar maple)	2–3
	Acer rubrum (red maple)	2–3
	Acer campestre (European maple)	2–3
½–1	Syringa vulgaris (lilac)	6–10
	Fagus sylvatica (European beech)	5–8
	Fagus grandifolia (American beech)	3–6
	Quercus robur (English oak)	3–6
	Quercus petraea (durmast oak)	3–6
	Quercus alba (white oak)	2–4
	Castanea dentata (chestnut)	2–4
	Tilia platyphyllos (large-leaved linden)	2–4
	Tilia cordata (small-leaved linden)	2–4
	Acer pseudoplatanus (sycamore maple)	2–3
¼–½	Prunus pennsylvanica (pin cherry)	3–6
	Acer pennsylvanicum (moosewood)	2–3
	Ginkgo biloba (ginkgo)	2–3
	Platanus acerifolia (London plane)	1–3
	Fraxinus excelsior (European ash)	1–3
	Prunus serotina (black cherry)	1–2
	Prunus Padus (European bird cherry)	1–2
	Alnus rugosa (smooth alder)	1–2
	Alnus glutinosa (black alder)	1–2
	Betula lutea (yellow birch)	1–2
	Betula papyrifera (paper birch)	1–2
	Betula populifolia (gray birch)	1–2
	Liriodendron tulipifera (tulip tree)	1–2
	Populus nigra (black poplar)	½–2
	Ulmus americana (American elm)	½–1
	Ulmus procera (English elm)	½–1
	Carya ovalis (small pignut hickory)	½–1

TABLE 1. (*Continued*)

Days in sunlight without water	Species	Days in sunlight with water
0–¼	Rhus typhina (staghorn sumac)	3–6
	Viburnum cassinoides (withe-rod)	½–2
	Populus grandidentata (big-toothed aspen)	½–2
	Populus tremuloides (trembling aspen)	0–½
	Fraxinus americana (white ash)	0–½
	Juglans cinerea (butternut)	0–½
	Robinia pseudoacacia (black locust)	0–½
	Salix nigra (black willow)	0–½
	Salix fragilis (crack willow)	0–½
	Salix pentandra (bay willow)	0–½
	Sambucus canadensis (elder)	0–½
	Ailanthus spp.	0–½

season. These species surveys, covering more than one hundred different kinds of plants of the north temperate and tropic zones, reveal a number of phenomena, some commonplace and expected; others, rather surprising.

Tropical species reacted much the same as temperate ones. The range in number of days that plants would retain a normal appearance in sunlight is about the same, both in trials with water and in trials without. Plants from the tropics, as a group, seemed to respond to water about the same as temperate plants, a few profiting immensely, most lasting two or three times as long with water as without, and some incapable of taking up sufficient water to prolong the fresh appearance. The amount of water required to keep a cut branch alive is considerably less than the amount transpired by the same branch before being cut. A cut six-foot branch will ordinarily require up to a quart or more of water the first day, and decreasing quantities thereafter until the branch is dead. Coniferous foliage ordinarily requires less water than hardwood foliage, probably because of its better protection against water loss.

Temperate Zone Foliage

The most obvious generality that may be stated upon the basis of temperate zone tests is the common observation that conifers of all types retain their normal appearance far longer than hardwoods. The poorest conifer tested (larch) lasted longer than the best hardwood (apple).

The other obvious tendency is that plants of the same genus tend to have similar lasting qualities regardless of species, locality, or origin. Certain genera were particularly consistent in this regard, among them being *Larix, Ligustrum, Alnus, Betula, Ulmus,* and *Salix*. In all cases, variation within the genus was far less than variation between the genera.

Species of several genera were more or less consistent, but yet reacted differently in various degrees. In some genera, species characteristic of drier sites — plants whose structure was better adapted to retaining moisture — apparently remained fresh the longest. Thus, red pine was somewhat better than Scotch pine, which, in turn, was definitely superior to white pine. A number of European species seemed to be somewhat better than their American counterparts, possibly because they had developed in a drier climate. Among these were European beech, European bird cherry, European ash, and European black poplar. This was not universally true, however, for the American maples lasted as well as the European hedge maple, and considerably longer than the European sycamore maple with its large thin leaves. The foliage of the latter, though, lasted longer than did the similar foliage of the American moosewood. When supplied with water, all five maples tested remained fresh for about the same period.

Among the oaks, the northern red oak was superior to the white oaks, both European and American, when tested in the absence of water. That the red oak group as a whole has greater lasting powers than the white oak group was substantiated by repeated tests not indicated in Table 1. With water supplied, little difference in reaction was noted.

Among the temperate species, the response to added water was relatively consistent. Practically all species benefited markedly from water except for a few plants which wilted and withered nearly as quickly with water as without. The response of staghorn sumac to a supply of water was exceptional. Cut sumac foliage would wilt the first day after being placed in water. Then, surprisingly enough, it would begin to recover. For several days thereafter, the leaflets would remain turgid, the plant being apparently normal except for a droop of the rachis. No other species tested showed this recovery from leaf-droop and wilt.

Tropical Zone Foliage

Tropical plants varied a great deal in their capacity to absorb water and in their lasting properties. Certain genera, such as *Casuarina*, *Ixora*, *Eugenia*, and *Eucalyptus*, lasted as much as five to fifteen times as long with water as without. Many others tested apparently were totally unable to utilize water (Table 2).

In one respect, tropical species behaved rather differently from temperate plants. Because of the large size and weight of many of the leaves, abnormal appearance was often first manifested by marked wilting of the petioles and consequent leaf droop, rather than by a change in the leaf itself. For instance, the leaves of the India rubber tree remained normal for two to four days after cutting, although petiole wilting rendered the plant abnormal in appearance in half that time. In the case of *Pandanus*, the leaves remained normal for six to twelve days, although severe stem droop occurred in half that period.

Among the palms, the coconut was among the several that lasted well. Others, however, whitened or drooped very soon after being cut. Foliage that was thick, heavy, shiny, and leathery, such as that of *Ficus*, *Rhizophora*, *Hernandia*, and *Barringtonia*, was moderately long-lived. Branches of these species were among those that drooped badly long before the leaves had begun to dry noticeably.

TABLE 2.

LASTING OF CUT TROPICAL FOLIAGE

Days in sunlight without water	Species	Days in sunlight with water
3–6	Calophyllum inophyllum (palo maria)	8–16
	Aralia spp.	8–16
	Cocos nucifera (coconut)—entire tree	8–16
	Cocos nucifera (coconut)—separate fronds	4–8
	Caryota spp. (fishtail palms)—separate fronds	4–8
	Ptychosperma spp. (MacArthur palm)—separate fronds	4–8
	Pandanus tectorius (screw pine)	3–6
1–3	Casuarina equisetifolia (Australian pine)	8–16
	Ixora spp.	8–12
	Mangifera indica (mango)	2–4
	Pongamia pinnata	2–4
	Acacia spp.	2–4
	Musa sapientum (banana)	1–3
	Ficus bengalensis (banyan)	1–3
½–1	Eugenia Jambos (rose apple)	8–16
	Barringtonia asiatica	2–4
	Livistona spp. (fan palms)—separate fronds	2–4
	Hernandia peltata	2–4
	Melaleuca leucodendron	2–4
	Morinda citrifolia	2–4
	Ficus elastica (India rubber tree)	1–2
	Guettarda spp.	½–1
	Rhizophora Mangle (mangrove)	½–1
	Sterculia foetida	½–1
¼–½	Eucalyptus algeriensis	4–8
	Corypha elata (giant fan palm)—separate fronds	1–2
	Hevea brasiliensis (rubber tree)	1–2
	Aleurites moluccana (candle nut)	½–1
	Terminalia Catappa (Indian almond)	½–1
	Thespesia populnea	½–1
0–¼	Dodonaea viscosa	1–2
	Bambusa spp. (bamboo)	½–1
	Hibiscus tiliaceus	¼–½
	Styloma pacifica (palm)—separate fronds	¼–½
	Erythrina spp.	0–¼

Few generalities can be drawn concerning the lasting of tropical foliage. This is due to the immense number of species in this zone and to the great difference in their size, structure, and growth habits. The fifty or sixty genera actually tested are sufficient only to tell us something of the range of lasting properties, of the reaction of some of the more important species, and of techniques useful in prolonging the lasting qualities of plants similar to those tested.

SELECTION AND HANDLING OF CUT FOLIAGE

The length of time that foliage of a given species will last is affected by

(1) the size of the branch, (2) the part of the tree from which it is cut, (3) the time of day, and (4) the time of year the branch is cut. The importance of these factors was repeatedly demonstrated.

The larger the branch, the longer it will last. This applies both to branches with and without water. For instance, a twenty-foot red oak tree, cut at the base and guyed upright in a canvas-lined hollow filled with water, lasted about ten days, while few red oak branches lasted more than six days. Small sprigs of red oak foliage ordinarily drooped in two or three days. Similar results were obtained with hemlock in many repetitions. In Florida, entire coconut trees cut at the base and placed in water lasted about twice as long as separate fronds. The superior lasting qualities of entire trees and large branches as compared to small branches is probably due to the water supply available in the reservoir of the trunk and large limbs. This water is drawn upon by the foliage long after the water supplied is no longer taken up through the base of the cut stem.

That the part of the tree whence the branch came affects the lasting of the foliage is easily demonstrable, but the results obtained are difficult to explain. In the case of temperate zone species tested, foliage grown in full sunlight lasts longer when cut than foliage grown in partial shade. Sprout foliage of red oak, red maple, and yellow birch grown in full sunlight lasted longer than shade-grown branches of the same species. This phenomenon is to be expected, as the leaves of the former type are better protected against water loss, having thicker blades, thicker cuticle, and fewer stomata. Yet tests in Florida showed that the upper sun-grown foliage of *Pongamia*, *Sterculia*, and the India rubber tree definitely did not last as long as the low shade-grown branches from the same trees.

It has long been known that foliage cut in bright sunlight and supplied with water withers more quickly than foliage cut during cloudy periods or at night and similarly treated. This fact was confirmed by tests with six northeastern hardwoods. In all cases, foliage cut at 5 A.M. lasted longer than that cut at 11 A.M. The greatest difference occurred in red oak. Branches of this tree cut at 5 A.M. lasted six days; at 7 A.M., four days; and at 11 A.M., two days. This effect was observed only when branches were supplied with water, and can be satisfactorily explained by air lock, a phenomenon discussed below.

As would be expected, immature foliage is poorer in lasting quality than hardened mature foliage. It follows that branches cut in the spring will not last as long as those cut later in the season. Hardwood branches cut in the fall, however, are inferior in their lasting qualities to those cut in mid-summer. This is because cutting the branch is apt to hasten autumn coloration, as in cherry and sumac; and, more important, is apt to hasten leaf abscission (many species). The rapid drop of leaves in autumn-cut branches more than compensates for the low loss of water from the mature foliage in cool weather.

Experiments with the use of synthetic plant hormones (auxins) indicated that, in certain instances, these substances had beneficial effects on the lasting qualities of cut foliage. It has been well established that auxin treatment retards the formation of the abscission layer, a principle utilized commercially by apple growers, and this retardation apparently may lengthen the life of branches cut in the fall. Also, auxin spray seems to maintain higher water content in leaves. It is further possible that auxin treatment influences metabolism, but it is difficult to determine whether the influence is direct or whether auxin influences metabolism by increasing water content by retarding abscission layer formation. The effect of the auxin treatment was observed in certain instances when branches were sprayed with water solutions (ca. 0.01%), but was more pronounced when applied in similar concentrations in combination with a wax emulsion spray (see below).

SUPPLY OF WATER

Cut foliage can be kept alive for extended periods as long as its moisture content can be maintained. The problem of supplying water is the limiting factor in the preservation of cut foliage. Once water no longer reaches the leaves, wilting and crisping quickly occur.

Plugging

Simply supplying water to the cut bases of branches does not necessarily keep the foliage fresh, as most plants have a wound reaction which plugs the cut stem and prevents water from reaching the leaves. The nature of this plugging is variable. It may be structural plugging, such as the development of tyloses and gum-like plugs in the vessels; it may be due to secretions such as latex and resin; it may be due to external agents such as bacteria and fungi; or it may be due to bubbles of gas in the vessels.

That plugging of vessels with tyloses and gum-like deposits is correlated with the cessation of water uptake in certain temperate plants was determined morphologically by Prof. R. H. Wetmore and Prof. I. W. Bailey, of Harvard University. In red oak, heavy tylosis formation takes place within a few days after cutting. In red maple, gum-like "amber" plugs develop in a similar period of time, mostly in the basal six inches. Both tyloses and "amber" plugs were formed very rapidly in willow.

In resinous plants, accumulations of exuded resin tend to seal off cut faces exposed to air. When the cut face is immediately placed in water, however, resin does not appear to interfere seriously with water uptake. Secretions of various tropical plants were much more troublesome. In particular, the latex of *Ficus, Hevea,* the mucilaginous sap of *Musa,* and similar secretions in representatives of other genera, tend to become suspended in the water, and in turn are drawn into vessels, where they form plugs at the first cross-wall.

It was further observed that films caused by bacterial accumulations occurred on the cut surfaces of stems containing no toxic substances such as tannin. These might well hinder water uptake, as would also extensive fungal activity.

In cut branches, air bubbles enter the vessels, forming "air locks," which presumably plug the stem and reduce water uptake. When the stem is cut, transpiration immediately draws air up through the cut surface into the stem. If the stem is then placed in water, the air is confined within and will form bubbles at the first effective cross-wall. This explains why foliage cut before sunrise lasts longer than that cut at mid-day. In full sunlight, the heavy transpiration of foliage draws air into the stem as soon as the stem is cut. Consequently, regardless of how quickly the stem is placed in water, enough air has entered the stem to form an air lock. Early in the morning, or at any other time that the transpiration rate is low, little or no air enters the stem if the cut base is promptly immersed in water.

Recutting

It is possible to prevent the formation of an air lock by cutting the branch under water. When bent through a pail of water and severed from the tree by being cut under water, aspen and white ash branches took up two to three times as much water as controls cut in the air. This enables them to last longer.

Such a procedure, though sound, is not very practicable. Once a branch cut in air has been placed in water, however, it can be recut under water advantageously. This will remove any plugging in the basal portion of the stem, whether due to tyloses, secretions, bacteria, or air locks.

The efficacy of the recutting treatment depends upon the species involved. It materially lengthens the life of those in which plugging occurs largely at the base, and is naturally of little value when plugging occurs throughout the stem. In trials at Petersham, the life of cut branches of sugar maple, red maple, beech, yellow birch, and hemlock was materially lengthened by recutting under water. Red oak, chestnut, sumac, and pin cherry were not materially aided. The results obtainable by recutting under water are occasionally spectacular. In one instance, a sugar maple branch taken in midwinter was kept alive for three months. By a combination of recutting and the basal injection of water with pressures up to 15 lbs. per square inch, a full crop of leaves was grown and maintained for many weeks.

Apparently species with a long functional vessel length are not helped by recutting, as the air locks and other plugs are not confined to the base of the stem. By testing cut segments of stems with eight to fifteen pounds air pressure applied to one end and collecting the air bubbles under water at the other, it was possible to calculate the approximate functional length of open vessels. This length was several feet or more for red oak, Lombardy poplar, white ash, elm, cherry, and ailanthus; several inches for red maple, sugar maple, yellow birch, and black walnut. In conifers, the tracheids are so short that such measurements were not made. The longest functional vessel lengths observed were 35 feet for red oak and 20 feet for Lombardy poplar.

Recutting a cut stem in air proved better than no treatment but inferior to recutting under water. This is to be expected, as the structural basal plugs are removed by the treatment, but air locks are not prevented from being reformed.

The lasting properties of lactiferous plants can be materially lengthened by washing the latex off the wound until it stops running, and also, to a lesser extent, by charring the base of the cut branch to coagulate the latex in the latex tubes, thereby preventing it from plugging the vessels.

Purity of Water

Water purity greatly influences the lasting of foliage, because impurities tend to clog up cut stems, thus reducing the rate of the water supply. This was demonstrated by trials at Petersham with sugar maple, red oak, beech, and hemlock. The reaction of sugar maple was typical. It lasted six days when supplied with water from a deep driven well; four days with clear, swift-flowing river water; three days with sphagnum swamp water; and two days with water from a stagnant pool. Water uptake for all species was closely correlated with lasting qualities.

In Florida, tests were carried out to see whether certain coastal species could be maintained with sea water. *Pongamia* and *Hernandia* were injured by salt water, and separate fronds of coconut quickly browned. Entire cut coconut trees and *Casuarina* were successfully maintained. In the case of coconut trees, the stem apparently filtered out the salt before the salt reached the foliage. Mangrove was successfully maintained in salt water as well as in fresh water only if the bases were cut under water and maintained there.

Extensive exploratory tests carried out by Dr. P. R. Gast and by the authors failed to reveal any chemical or combination of chemicals which when added to the water supply was much more effective in prolonging the fresh appearance of cut foliage than the use of water alone.

Method of Supply

The most obvious and most practicable means of supplying water to cut foliage is through cut bases. Water may also be made available to the plant in other ways.

Merely placing the cut bases in moist soil is sufficient to prolong the life of coniferous branches. A certain amount of water is supplied by capillary action, although this method is much inferior to standing the cut base in clean water. The value of placing coniferous stems in the ground was demonstrated by a number of tests, both indoors and outdoors, one of which is detailed in Table 3. Hardwoods require so much water that they are not helped by this treatment.

Water was also supplied through incisions in the stem, either made by a sharp blade or by an auger, and through the stubs of cut laterals. In the experiment summarized in Table 3, the amount of water taken up by hemlock foliage through cut bases and cut laterals was roughly proportional to the surface area of the sapwood exposed in the cuts. The most successful treatment, exclusive of wax treatments, was that in which water was supplied both through the cut base and a cut lateral.

Cut foliage can be maintained for long periods of time by placing the bases in sand and preventing the tops from drying out with an intermittent spray. In such a case, the rate of water loss is reduced to a very low level,

TABLE 3.

WATER SUPPLY AND WAX TREATMENT OF CUT HEMLOCK TREES[1]

Treatment	Water content[2] (percent)				Water uptake in 17 days (cc. per gr. total dry wt.)	Leaf fall (percent)	
Base in	13 days	27	40	80		40 days	80
Air	34	12	7	3		100	100
	37	14	8	3		100	100
Soil	49	36	24	3		10	100
	49	39	19	11		30	100
Air—one lateral	42	17	7	3	.047	100	100
with water	42	19	8	3	.051	100	100
Air—two laterals	44	31	14	3	.057 + .064	96	100
with water	41	21	9	3	.031 + .057	100	100
Water	54	55	40	3	.854	0	100
	55	55	48	3	.717	0	100
Water—one lateral	54	55	55	38	.607 + .059	0	0
with water	56	56	56	8	.738 + .076	0	70
Air—sprayed	48	31	18	3		40	100
with Dowax[3]	41	34	9	3		100	100
Air—sprayed	48	45	40	7		0	95
with wax solution[4]	46	44	44	5		0	30
Water—sprayed	54	54	49	4	.582	0	95
with Dowax	53	53	48	5	.464	0	95
Water—sprayed	54	56	57	40	.259	0	3
with wax solution	55	55	56	43	.393	0	6

[1]Tree six to eight feet tall placed in large room on December 16, 1942. Average daily range in temperature, 45 to 60° F. Average relative humidity, 50%.

[2]Original water content, average for all trees, 54%. All values below 35% represent fallen needles.

[3]One part Dowax to four parts water.

[4]One part paraffin to one part petrolatum to eight parts kerosene.

and enough water is taken up by the leaves to make up any deficit which may occur. The stems may be heavily plugged, but the development of new xylem will re-establish translocation after roots are formed. An automatic apparatus to accomplish this was constructed at the Harvard Forest, which maintained leafy cuttings of various species for the entire growing season.[4] Maintenance of this type is of no value in camouflage, but is a promising tool in the rooting of leafy cuttings.

REDUCTION OF WATER LOSS

Inasmuch as loss of water is the primary cause of the death of cut foliage, it follows that any method which reduces water loss without otherwise affecting the plant will increase the period of normal appearance. The principal way of accomplishing this is to coat the foliage with a non-toxic substance, usually a wax or a mixture containing wax.

In the course of the present investigations, a great deal of exploratory work was carried on to investigate the possibilities of this type of treatment. A large number of substances were tried in many combinations under a variety of conditions. Although no material was found which could be highly recommended, enough was learned to reveal the limitations and possibilities of this means of reducing water loss.

A satisfactory coating must have two properties: it must form a thin pliable inconspicuous film capable of markedly reducing water loss, and it must be non-toxic to the living tissue of the plant. Unfortunately, these two characteristics rarely occur together.

The effectiveness of a film in reducing water loss may be determined by observations of the lasting quality of branches, by measuring water uptake, by measuring changes in total plant weight, and by determining moisture content. Observation suffices only to distinguish living foliage from dying and dead foliage. Water uptake may be used as an index of water loss, especially for longer time periods. Thus, in Table 3, the hemlocks sprayed with wax solution required less water and lasted better than trees sprayed with Dowax. Moisture content, whether determined directly from samples, or indirectly by measuring the loss of weight of a drying cut branch, is an index of the ability of the coating to reduce water loss. This, too, is illustrated in Table 3.

Death of living tissue is indicated by color and structural changes which markedly alter the normal appearance of the plant. Any substance causing the death of tissue, therefore, is undesirable as a protective coating. Toxicity is governed by a large number of factors, such as temperature, method of application, and chemical composition of the coating. Chemicals toxic to foliage even in a low concentration are not necessarily toxic in combination, as in the case of ammonium hydroxide in Emulsion B, Table 4. Most of the coatings tried in the present investigation proved to be toxic in one way or another. Conifers are much more resistant to

[4]Grossenbacher, Karl A. An apparatus to maintain a surface film of water for use in vegetative propagation. Jour. Arnold Arb. 26: 206–211. 1945.

TABLE 4.

TESTS IN FULL SUNLIGHT WITH WAX EMULSION DIPS ON BRANCHES SUPPLIED WITH WATER

Species	Control	Dowax[1]	Emulsion A[2]	Emulsion B[3]
	Average number of days before reaching Class III			
Red oak	4	6	8	5
White oak	3	5	8	6
Chestnut	4	2	6	5
Beech	4	3	6	3
Paper birch	2	1½	3	2
Elm	1	1	1	1
Aspen	0	0	1	0

[1]One part Dowax to three parts water.

[2]Paraffin, 7.7g.; Duponol WS, 2.3g.; linseed oil, 3.5ml.; glue, 1.0g.; water, 200ml.

[3]Candellila wax, 5.0g.; Neomerpin, 1.0g.; Ammonium hydroxide, 4.0g.; kerosene, 4.2ml.; water, 6.3ml. Concentrate diluted, one part to three parts water.

toxic effects than hardwoods. The development of a non-toxic coating is the principal difficulty in solving the problem of how effectively to reduce water loss and maintain living foliage.[5]

Coatings fall into two general classes: solutions and emulsions. Solutions of various waxes in organic solvents are highly effective in preventing water loss. Most of the solvents, however, are highly toxic to living tissue. The most promising solution used was a mixture of one part paraffin and one part petrolatum in eight parts of kerosene. This proved extremely effective in preventing water loss (Table 3), and of low toxicity when sprayed on foliage at such a temperature that the film solidified as soon as it was formed. It was very toxic, however, when used at higher temperatures, or when applied as a dip. In these cases, greater penetration occurred, and penetration of any coating was found to be conducive to toxicity.

Emulsions have a basic advantage over solutions in that they may be applied in a non-toxic medium — water. Among the emulsions tested, a commercial preparation known as Dowax proved reasonably efficient in prolonging the life of conifers but not of many hardwoods (Tables 3 and 4). It was toxic in varying degrees with several of the plants tried. Experiments made by Dr. P. R. Gast in Florida indicated that its use materially prolonged the life of fronds of the cabbage palm (*Sabal palmetto*) and the leafy foliage of blackjack oak (*Quercus marilandica*). Auxin treatment, as mentioned above, apparently lengthened the life of cut foliage somewhat when used with Dowax on branches supplied with water. This

[5]Comar, C. L., and Barr, C. G. Evaluation of foliage injury and water loss in connection with use of wax and oil emulsions. Plant Physiology **19**: 90–104. 1944.

emulsion was developed by E. J. Miller[6] and contains a wax, an ammonium salt of a drying acid, and a colloidal earth.[7]

Emulsion A (Table 4, footnote 2) was the most promising developed in the present investigations. It is a non-ammonical mixture but inconvenient in that it cannot be prepared in a concentrated form. For hardwood foliage it was of low toxicity and highly effective in reducing water loss. This emulsion was developed by Dr. Ernest Ball, of Harvard University, who participated actively in the development of satisfactory coatings.

Emulsion B (Table 4, footnote 3), an ammonical mixture which could be prepared in a concentrated form, was also effective in reducing water loss. The emulsifiers used in this and other emulsions, as well as certain other chemicals, were provided by the E. I. Dupont de Nemours Company.

All the coatings mentioned above are effective only when water is supplied to the treated foliage. Without water, improvement was noted only in certain cases. The lasting of conifers could usually be lengthened somewhat. Emulsions A and B also helped certain hardwoods, such as red oak and paper birch. This limited effect in the absence of water is to be expected, inasmuch as a protective coating is of value only in reducing water loss to a rate comparable with that of water uptake, thus keeping the plant tissue alive. If water is not supplied, a protective coating can lengthen life only a short time by retarding the loss of water already present in the plant.

SUMMARY

Extensive investigations were carried out to determine how long cut foliage of different species will retain its normal appearance under various conditions, and how the life of cut foliage can be maintained.

More than one hundred representative species of the northeastern United States, western Europe, Asia, and the tropics were tested and classified as to their lasting qualities, both with and without a supply of water.

Conifers proved to be greatly superior to hardwoods in their lasting qualities. Plants of the same genus tended to have similar lasting qualities regardless of their geographic origin.

The range in lasting qualities of tropical species was much the same as that of temperate plants. In the tropics, however, because of the large size and weight of many of the leaves, abnormal appearance of drying foliage often was first manifested by marked wilting of the petioles and consequent leaf drooping, rather than by a change in the leaf itself.

A number of factors involving the selection and handling of cut foliage affect their lasting qualities. The larger the branch, the longer it will last. Foliage grown in full sunlight generally lasts longer than shade-grown foliage, although upper sun-grown branches of certain tropical species were found to be inferior to lower limbs grown in the shade. Mature foliage

[6]Miller, E. J., Meilson, J. A., and Bandemer, Selma L. Wax emulsions for spraying nursery stock and other plant materials. Michigan Agr. Exp. Sta. Spec. Bull. 282. 39 pp. 1937.

[7]U. S. Patent no. 2,013,063.

lasts better than immature, but late season foliage does not last as well because of abscission layer formation. In certain instances, auxin treatment has beneficial effects on the lasting qualities of cut foliage, both in retarding abscission and in maintaining water content.

Supplying water generally increases the life of foliage two to four times. Water ceases to reach the leaves, however, in a few days, due to plugging of the stem. This plugging may be due to tyloses or gum-like deposits in the vessels, to secretions, such as latex or resin, to bacteria or fungi, or to air locks—bubbles of air in the vessels. By cutting foliage when the transpiration rate is low (during rains, early in the morning, etc.), plugging from initial air locks can be minimized.

In plants with functionally short vessels, where plugging occurs mainly in the basal portion of the stem, recutting the stem under water will remove the plug and materially increase the life of the foliage.

Cut foliage lasts best in pure water, as solid particles clog the vessels and chemical impurities may injure the living tissues. Salt water (sea water), however, successfully maintained cut branches of a few tropical coastal plants.

No chemical or combination of chemicals was found which would increase the lasting of cut foliage.

Water can be successfully applied to cut branches through the base, through cut laterals, and through stem incisions.

The reduction of water loss by means of a non-toxic coating will materially increase the life of cut foliage. Despite extensive experiments, no highly successful coating was developed. Several coatings however, were satisfactory under certain conditions. Among these coatings were one solution of paraffin and petrolatum and two emulsions: a non-ammonical one with paraffin, and an ammonical one with candellila wax. Waxy coatings are particularly effective when the treated foliage is supplied with water. The most satisfactory coatings approximately double the life of many species.

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